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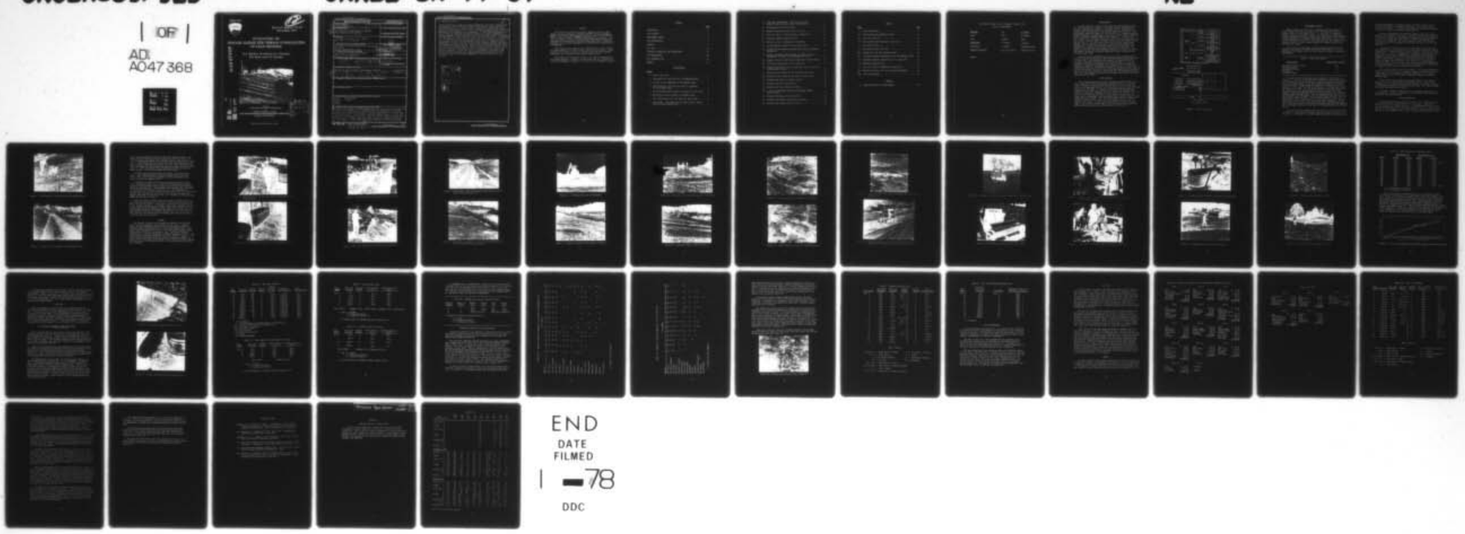

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UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD REGIONS

D.A. Gaskin, W. Hannel, A.J. Palazzo,
R.E. Bates and L.E. Stanley

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A terrain stabilization research/demonstration site was constructed in May 1974 at Hanover, New Hampshire, to investigate various combinations of physical, chemical and biological techniques for terrain stabilization in cold regions. Fourteen test plots (10x40 ft) with individual 350-gal. tanks to collect sediment were installed on a 16° slope. These 14 test plots were to examine the effectiveness of sewage sludge and primary effluent on terrain stabilization in cold regions. In 13 of the 14 plots the variables studied were nutrient

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source (fertilizer, sludge and primary wastewater), moisture (irrigated and nonirrigated), erosion control material (jute netting, straw tacked with a tacking compound, and no erosion control material) and vegetation (three grasses and two legumes). The control plot was left bare of seed, fertilizer and erosion control material for comparison. A 20,000-ft^2 area adjacent to the 14 plots was installed for general testing of various combinations of tacking chemicals, plastic netting, straw, and wood fiber mulch. In general, all treatments with the exception of two plots were effective in reducing soil loss in comparison with the control which had a loss of 34,531 lb of soil (dry weight) on a per acre basis. The effectiveness of treatment based on comparison of the soil loss for the individual treatment against the control plot ranged from 89.6% to 99.8%. There is strong indication from the sediment loss data collected that the sludge is acting both as a nutrient source and as an erosion control material (net) by reducing runoff velocity and absorbing moisture. If the soil loss is considered as a function of the nutrient source in groups, the sludge-treated plots average 150 lb, the fertilized plots 814 lb and the wastewater plots 981.7 lb of soil loss per acre.

PREFACE

This report was prepared by David A. Gaskin, Geologist, Wayne Hannel, Biologist, Antonio J. Palazzo, Research Agronomist, Roy E. Bates, Meteorologist, and Leonard E. Stanley, Research Physicist, of the U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by DA Project 4A762720A896, *Environmental Quality for Construction and Operation of Military Facilities,* Task 04, *Land Use Planning,* Work Unit 003, *Revegetation of Terrain After Construction in Cold Regions.*

The authors wish to express their appreciation to Judith Zimicki and Timothy Buzzell for their technical review of this report. Appreciation is also given to the U.S. Army Meteorological Team, Hanover Detachment, for collecting meteorological support data.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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Conversion Factors: U.S. Customary to Metric (SI)
Units of Measurement

Multiply	by	to obtain
inch	25.4*	millimeter
foot	0.3048*	meter
pound-mass	0.4535924	kilogram
pound/acre	1.120847	kilogram/hectare
degrees Fahrenheit	$t_{°C}=(t_{°F}-32)/1.8$	degrees Celsius

*Exact

INTRODUCTION

In early May 1974, a terrain stabilization research/demonstration site was constructed at CRREL to investigate various combinations of physical, chemical and biological techniques for the stabilization of terrain after construction in cold regions (Gaskin et al. 1974). The experimental design was based upon the utilization of sewage sludge and primary wastewater in combination with various erosion control materials, mulch, fertilizer, tacking compounds and vegetation. Fourteen test plots (each 10 x 40 ft) were installed on 16° slope with individual 350-gal. runoff collection tanks to measure sediment loss and monitor water quality (Fig. 1). In 13 of the 14 plots the variables studied were nutrient source, moisture requirement, erosion control material and vegetation. A control plot was left bare of seed, fertilizer, and erosion control material for comparison with the treated plots. In addition, five test plots were installed adjacent to the 14 test plots for general testing of two tacking compounds, plastic netting, wood fiber mulch and straw.

Construction on the CRREL Terrain Stabilization Research/Demonstration site was initiated on 6 May 1974 and completed during the week of 20 May 1974. The experiment was designed to compare individual treatment variables on plots 1-13 to the control, plot 14. For comparison of the various treatments, data were collected on daily precipitation, average daily temperature, sediment loss, soil temperature, vegetation production, vegetation distribution and water quality (App. A). On the five adjacent test plots only vegetation productivity was measured. Data collection was initiated in early June 1974 and continued through June 1975. This report will discuss the design, construction and results from the 1974-75 study.

SITE LOCATION

The research/demonstration site is located on CRREL property on a steep slope (16°) near the greenhouse laboratory (Fig. 1). The test area is located on former glacial Lake Hitchcock of the Pleistocene epoch in the Quaternary period. The soil within the test area, delineated by plots 1-14 in Figure 1, consists of wind-blown fine-grained silt classified as ML under the Unified Soil Classification System (USA). Gravel fill has been intermixed with the natural soil in plots 1-7. The soils in plots A-E are a mixture of sand, gravel, boulders and silt dumped over the embankment from the parking area located directly up the slope from the test area. This area was reshaped using a bulldozer to conform with the general slope of the area marked as plots 1-14 in Figure 1 (16° slope). A small berm was constructed across the upper edge of the slope to prevent runoff from the parking and storage area directly above the study site from entering the test plots.

Plot No.	Vegetation	Moisture	Nutrient Source	Erosion Control
1	Grass Seed*	none	Fertilizer 15-15-15	Jute Net
2				Terra Tack I w/straw
3			Sludge	Jute Net
4				Terra Tack I w/straw
5		Irrigate	Fertilizer 15-15-15	none
6				Jute Net
7				Terra Tack I w/straw
8			Sludge	none
9				Jute Net
10				Terra Tack I w/straw
11		Wastewater	Wastewater	Terra Tack I w/straw
12				Jute Net
13				none
14	none	none	none	none
A	Grass Seed	—	Fertilizer 15-15-15	Terra Tack I w/plastic net
B				Terra Tack II w/straw
C				Terra Tack II
D				Terra Tack II w/fiber mulch
E				Dow Chemical w/straw

*N.H. Department of Highways Seed Specification

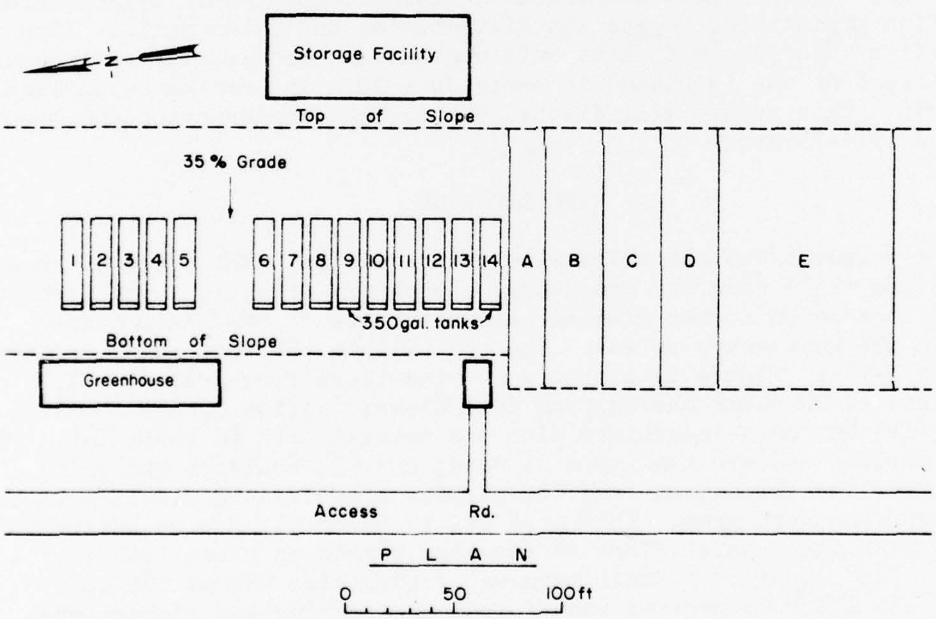

Figure 1. Plan of test site.

EXPERIMENTAL DESIGN

These fourteen test plots were to examine the effectiveness of sewage sludge and primary effluent as soil stabilization factors on sloping terrain in cold regions (Fig. 1). The source of sludge and primary effluent was domestic sewage. The sludge was an aerobically digested, dewatered and aged on drying beds for one year. The objective of the experiment was to compare individual treatments on plots 1-13 to control conditions on plot 14. Each individual plot was equipped with a 350-gallon tank to collect eroded sediment for comparison with other plots and the control.

All plots were seeded using a seed mixture employed by the New Hampshire Department of Highways and Public Works (Table I), with the exception of the control plot 14, which was left stripped of vegetation and unseeded.

Table I. Slope seed mixture.

Kind of Seed	Application (lb/acre)
Tall Fescue (Alta or K31)	20
Perennial Ryegrass	15
Creeping Red Fescue	5
Red Clover	5
Birdsfoot Trefoil	5

The nutrients for plant growth were supplied in three ways. On plots 1, 2, 5, 6, and 7, nutrients were supplied by 15-15-15 fertilizer at 5.6 lb per plot or 610 lb per acre. This application rate was based on the test specification of the New Hampshire Department of Highways and Public Works. Sewage sludge was applied as a nutrient source on plots 3, 4, 8, 9, and 10 at 420 wet lb per plot (47.9% moisture content) or 45,780 lb per acre. On a dry weight basis the nitrogen content of the sludge was 1.07%, and phosphoric acid content was 2.84%. The anaerobic digested sludge was obtained from the Hanover, New Hampshire, primary sewage treatment plant. For the remaining plots (11, 12, 13), the nutrient source selected for testing was primary effluent from the CRREL sewage treatment plant. The irrigation rate was 50 gal. per application, which is equivalent to 0.2 in. per application. Effluent was applied at this ratio on an "as needed" basis depending on clover wilt. The total amounts of nitrogen, phosphorus, and potassium supplied by the wastewater were 25.6, 6.9, and 4.2 lb respectively, on a per acre basis.

The initial surface stabilization for plots 1, 3, 6, 9, and 12 was by jute net. Straw tacked with Terra Tack I was used on plots 2, 4, 7, 10, and 11. Terra Tack I, a natural vegetable powder containing gelling

and hardening agents, is mixed with water to form a highly viscous slurry. The objective in testing Terra Tack I was to tack straw to straw and to the soil. No physical stabilizing controls were employed on plots 5, 8, and 13, as on the control plot 14.

Moisture requirements for vegetative growth on plots 1-13 were supplied in three ways. For plots 1-4 and 14, reliance was on natural precipitation. Water and wastewater were applied on an as-needed basis on plots 5-13, based upon clover wilt. Moisture applications were measured by a flowmeter. The rate chosen was 50 gal. per plot per application, which is equivalent to 5450 gal. per acre or 0.2 in. per application.

In addition to the 14 plots thus far described, five large plots were installed in the adjacent area for more general testing of various combinations of tacking chemicals, plastic netting, straw and wood fiber mulch (Fig. 1). Each plot (designated A through E) received the seed mixture and fertilizer recommended by the New Hampshire Department of Highways and Public Works. Plot A was designed to receive an application of Terra Tack I directly on bare soil, then to be covered by plastic netting. The objective of this test was to lock the seed, fertilizer and netting to the bare soil as the sprayed soil was exposed to drying conditions. The crust formed by the chemical is reported to be semiporous when exposed to rainfall or irrigation.

Plot B was designed to test Terra Tack II as a tacking compound for straw. Terra Tack II is a two component mix for tacking straw or wood fiber mulch for soil moisture retention. Component A is a seaweed extract which is mixed with water. Component B consists of a polymerizing agent.

Plots C and D were designed to test Terra Tack II as a binder on bare soil (plot C) and with wood fiber mulch (plot D). Plot E was designed to test an experimental tacking chemical (latex base) produced by Dow Chemical Company for tacking straw to straw. The latex is mixed with water and sprayed on the straw.

The table in Figure 1 summarizes all the various combinations of seed, moisture, nutrient, and erosion control methods which were chosen during the site design process.

SITE CONSTRUCTION

The fourteen test plots, each 10 ft wide by 40 ft long, were laid out during the week of 6-10 May 1974 on a 16° slope. A three-foot buffer zone was left between each plot. A desodding machine was used to cut the existing sod on the individual test plots (Fig. 2). The cut sod was left in place from 8 May to 15 May to protect the slope against sediment loss. The embankment was cut with a small bulldozer (Fig. 3), and

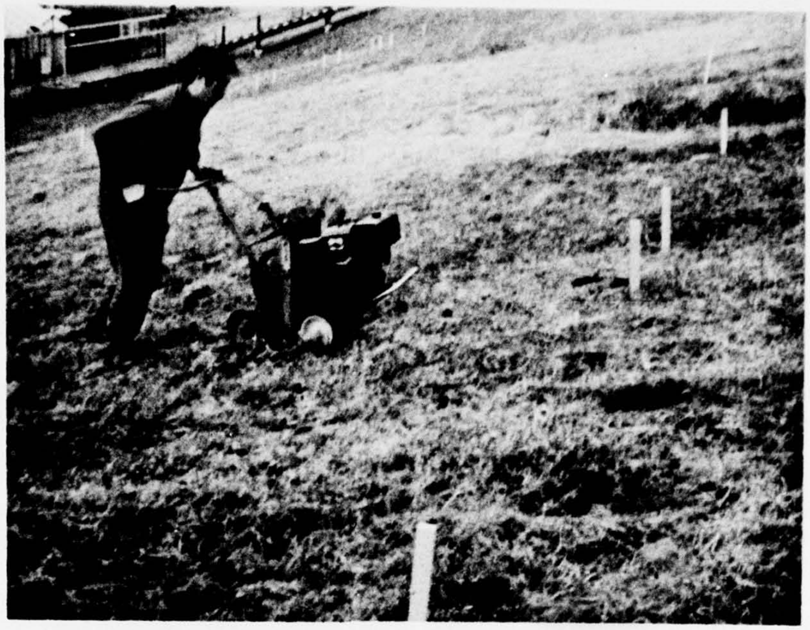

Figure 2. Individual plot being cut with a desodding machine.

Figure 3. Initial cut for placement of the sediment tanks.

then individual sediment collection tanks were placed by hand at the lower end of the test plots after leveling the site (Fig. 4-5). The soil was pushed back against the individual tanks by the bulldozer (Fig. 6-7). A small earth berm was built on the lower slope above the greenhouse to divert drainage to the south (Fig. 8). Jute netting was then placed downslope from and between the collection tanks to retard erosion (Fig. 9). Straw was placed further downslope from the jute netting after seeding. The straw was tacked with Terra Tack I.

The fertilizer and sludge were top dressed on the appropriate plots. Grass seed was added, followed by either straw or jute net (Fig. 10-12). Terra Tack I was sprayed on plots containing straw. Figure 13 shows the completed plots.

Preparation of plots A-E was started during the week of 20 May 1974. As shown by Figures 14, 15, and 16, the site had very little vegetation and contained several major erosion gullies which developed during the previous year. The embankment was reshaped with a bulldozer to conform with the adjacent slope (Fig. 17). The embankment was dragged with a wire net loaded with concrete blocks (Fig. 18). Fertilizer and seed were applied with a spreader to conform with New Hampshire Highway Department specifications (Fig. 19). Individual plots were then marked out as shown in Figure 1.

Straw was spread on plots B and E and plastic netting on plot A by hand prior to being tacked by Terra Tack I on plot A, Terra Tack II on plot B and latex on plot E. Terra Tack I and II were put into solution in two separate operations in a 250-gal. tank using a portable pump and a hose connected to the greenhouse water supply (Fig. 20 and 21). The experimental latex-base tacking agent was mixed in a 250-gal. tank by a representative from the Dow Chemical Company (Fig. 22). A 1-1/2-in.-diam. hose was laid upslope and the chemicals were applied from the top to bottom (Fig. 23, 24, and 25).

CLIMATE

The climate of central and northern New England is the woodland type of the cool-temperate zone (Landsberg et al. 1965). Climatological normals used were extracted from the long-term Hanover, New Hampshire, data (Climatological Data, New England Summary 1964). Mean annual total precipitation is 37.3 in. with the normal maximum monthly precipitation of 4.18 in. occurring in July. The lowest recorded temperature is -40°F and the highest recorded temperature is 101°F. The 30-year long-term normal temperature is 44.8°F. Table II shows: 1) the normal monthly precipitation and the monthly temperature normals for Hanover and 2) the monthly precipitation totals and mean monthly temperatures from April 1974 through June 1975 (U.S. Army Meteorological Team Data, monthly).

Figure 4. Hand leveling of the area just prior to placement of the sediment tank.

Figure 5. The tank being placed against the edge of the test plot.

Figure 6. Backfilling the area around the sediment tanks.

Figure 7. Soil being pushed up to the tanks for final grade.

Figure 8. Final grade. Note small berm on lower slope to retard erosion during construction.

Figure 9. Final tank installation. Note jute net around tanks for erosion control during construction.

Figure 10. De-sodding test plot with backhoe.

Figure 11. Backhoe stripping two-inch layer of cut sod.

Figure 12. Four test plots in various stages of completion.

Figure 13. Completed sediment tank test plots.

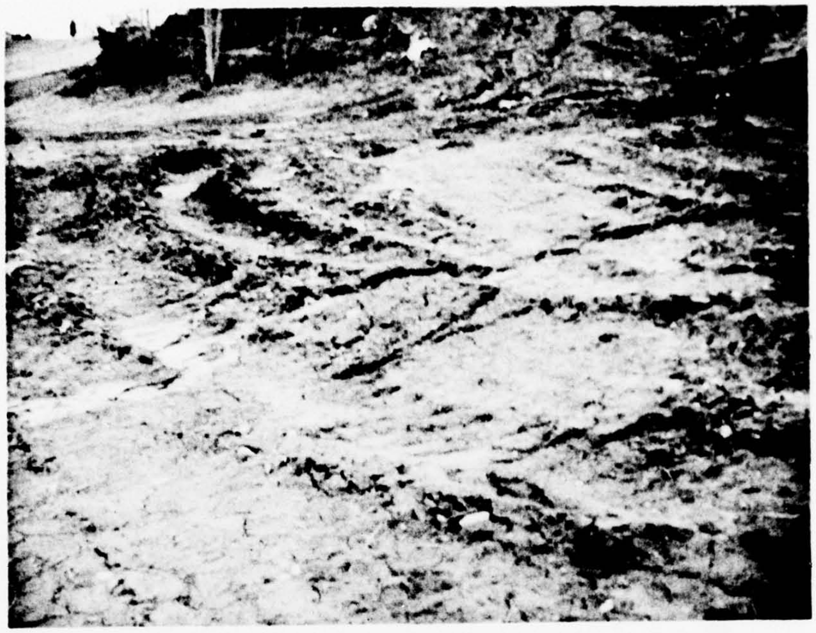

Figure 14. Test area prior to reshaping by bulldozing.

Figure 15. Looking downslope across the large test area.

Figure 16. Erosion ditches caused by running water from the adjacent parking lot.

Figure 17. Initial cut made by the bulldozer to reshape slope to approximate the shape of the adjacent test area.

Figure 18. Dragging slope with wire fence loaded with concrete block.

Figure 19. Fertilizing slope with 15-15-15 fertilizer.

Figure 20. Mixing Terra Tack II into the wood fiber mulch using high pressure water streams.

Figure 21. Pump used to mix Terra Tack II and wood fiber mulch.

Figure 22. Mixing Dow latex chemical just prior to application.

Figure 23. Spraying Terra Tack II directly on soil.

Figure 24. Tacking straw with Terra Tack II.

Figure 25. Spraying Dow latex chemical on straw.

Table II. Precipitation and temperature data.

Month	TEMPERATURE (°F) Normal	(74-75)	PRECIPITATION (in.) Normal	(74-75)	
Apr	43.4	43.0	3.13	1.69	
May	55.3	53.0	3.30	3.21	1.10(1)
Jun	64.6	64.0	3.30	2.96	
Jul	69.2	69.0	4.18	2.34	
Aug	67.2	68.0	3.07	3.66	
Sep	59.4	59.0	3.38	5.47	
Oct	48.3	42.0	2.82	1.27	
Nov	36.5	34.0	3.36	3.48	
Dec	22.9	27.0	2.72	2.02	
Jan	19.2	21.0	2.87	2.91	
Feb	20.9	21.0	2.40	1.73	
Mar	30.5	28.0	2.77	1.99	
Apr	43.4	39.0	3.13	2.64	
May	55.3	60.0	3.30	1.10	
Jun	64.6	63.0	3.30	3.00	0.43(2)

(1) Precipitation 17-31 May 74
(2) Precipitation 1-5 June 75

Total precipitation was measured by an 8-in. standard recording rain gage for the duration of the experiment, 17 May 1974 through 5 June 1975. A plot of the long-term normal precipitation is plotted against the recording rain gage data in Figure 26. These plots show that accumulated precipitation amounts remained below normal throughout the entire experiment. The total accumulated precipitation approached normal at the end of September 1974 only, when the monthly precipitation was 2.09 in. greater than normal (Table II). Figure 26 also shows that the precipitation trend continued to be less than normal after 30 September. By the end of the experiment, the total accumulated precipitation amount at the CRREL site was 33.10 in., which is 6.40 in. less than normal.

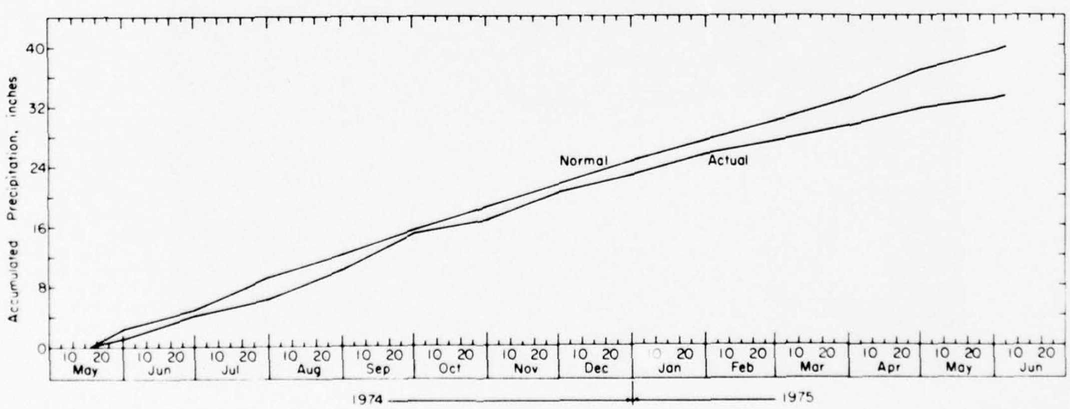

Figure 26. A plot of accumulated precipitation against normal precipitation.

Air temperature averaged 46°F from April 1974 to June 1975 compared to the normal temperature for the same period of 47°F. The monthly temperatures in Table II show that: 1) October 1974, March and April 1975 were 6°, 2°, and 5°F colder than normal respectively, 2) the winter months of December and January, plus May, 1975 were warmer than normal by 4°, 2°, and 5°F respectively, and 3) the other monthly temperature values on Table II were nearly normal.

SOIL LOSS

With the exception of plots 6 and 13 all treatments were very effective in reducing soil loss in comparison to the control plot (Table III). The control plot on a dry weight basis had a loss of 34,531 lb of soil on a per acre basis. The effectiveness of treatment based on comparison of the soil loss for the individual treatment against the control plot ranged from 89.6% on plot 6 to 99.8% on plot 4 (Table III). The effectiveness of treatment is defined as the amount of soil retained (not eroded) as compared to plot 14. The effectiveness of treatment in percent for plot J, where J is one of plots 1-13, is calculated from

$$100 \left(\frac{\text{Plot 14 soil loss - Plot J soil loss}}{\text{Plot 14 soil loss}}\right).$$

Plot 6 had the high loss with 3584 lb of soil lost per acre. The sediment collection tank for this plot was located against a sand seam in fine-grain soil (Fig. 27). During periods of heavy rain the sand seam received a large amount of water from the parking area located just east of the test plots. The resultant movement of the tank and agitation of the tank lip against the trench wall resulted in an abnormally large deposition in the tank (Fig. 28).

There is a strong indication from sediment loss data collected that the sludge is acting both as a nutrient source and as an erosion control material (net) by reducing runoff velocity and absorbing moisture (Table III). Also, the data from Table III suggest that the nonirrigated plots (1,2,3, and 4) for erosion control-nutrient pairs performed better in minimizing erosion than plots that were irrigated.

The effectiveness of the sludge for erosion control material is further emphasized by comparing soil loss per parameter. As shown in Table IV for straw tacked with Terra Tack I, the plots treated with sludge were the most effective against sediment loss. Plots 4 and 10 were 99.8% effective in reducing soil erosion, losing 64.5 and 66.7 pounds of soil per acre as compared to 34,531 lb/acre for the control. A comparison of individual plots treated with jute net in Table V again demonstrates that sludge is acting both as a nutrient source and as an erosion control material. Table VI expresses the soil loss for plots that received no erosion control material. Again, sludge-treated plot 8 was 99.1% effective.

Figure 27. Sand seam located in fine-grain soil.

Figure 28. Sediment tank removed after heavy rainstorm.

Table III. Soil loss (1974-75).

Plot Number	Soil Loss (lb/acre[1])	Erosion Control	Nutrient Source	% Effectiveness of Plots[2]	Estimated Cost ($/acre[3])	Total Moisture (in.)
4	64.5	TTS	S	99.8	421.60	33.1
10	66.7	TTS	S	99.8	1,371.60	36.9
11	134.9	TTS	W	99.6	1,551.60	38.1
3	154.0	JN	S	99.5	1,687.60	33.1
9	172.8	JN	S	99.5	2,637.60	36.9
12	254.7	JN	W	99.3	2,827.60	38.1
8	295.2	N	S	99.1	1,121.60	36.9
2	463.7	TTS	F	98.7	325.98	33.1
5	616.2	N	F	98.2	1,027.64	36.9
7	1037.9	TTS	F	97.0	1,275.98	36.9
1	1039.2	JN	F	96.7	1,601.98	33.1
13	2555.4	N	W	92.6	1,301.60	38.1
6	3584.4	JN	F	89.6	2,551.98	36.9
14	34531.0	N	-	----	--------	33.1

1 - Dry weight
2 - % effectiveness of treatment against control plot 14
3 - Includes irrigation cost for plots 5-13
TTS = Terra Tack I and Straw
N = No erosion control
JN = Jute netting
F = Fertilizer (15-15-15)
S = Sludge
W = Primary wastewater

Table IV. Straw tacked with Terra Tack I-soil loss.

Plot Number	Soil Loss (lb/acre)	Nutrient source[1]	Total Moisture (in.)	% Effectiveness of Plot[2]
Plot 4	64.5	S	33.1	99.8
10	66.7	S	36.9	99.8
11	134.9	W	38.1	99.6
2	463.7	F	33.1	98.7
7	1037.9	F	36.9	97.0

sum = 1767.5 Average = 353.5

1 - Key S = Sludge
W = Primary wastewater
F = Fertilizer (15-15-15)

2 - % Effectiveness of treatment against control plot 14

Table V. Jute net-soil loss.

Plot Number	Soil Loss lb/acre	Nutrient Source[1]	Total Moisture (in.)	% Effectiveness of Plot[2]
Plot 3	154	S	33.1	99.5
9	172.8	S	36.9	99.5
12	254.7	W	38.1	99.3
1	1139.2	F	33.1	96.7
6	3584.4	F	36.9	89.6

Sum = 5305.1 Average = 1061 (Sum = 1720.7, average = 430.1, neglecting 6)

1 - Key S = Sludge
W = Primary wastewater
F = Fertilizer (15-15-15)

2 - % effectiveness of treatment against control plot 14

Table VI. No erosion control soil loss.

Plot Number	Soil Loss lbs/acre	Nutrient Source[1]	Total Moisture (in.)	% Effectiveness of Plot[2]
Plot 8	295.2	S	36.9	99.1
5	616.2	F	36.9	98.2
13	2555.4	W	38.1	92.6
14	34531.0	-	33.1	---

Sum = 3466.8 Average 1155.6 (neglecting no. 14)

1 - Key S = Sludge
F = Fertilizer (15-15-15)
W = Primary wastewater

2 - % effectiveness of treatment against control plot 14

If sediment loss is considered as a function of the nutrient source in groups (Table VII), the sludge treated plots averaged 150.6 lb of soil loss per acre, the wastewater treated plots 981.7 lb of soil loss per acre and the fertilized plots 814 lb soil loss per acre (neglecting plot 6). Had plot 6 been included the fertilized plots would average 1368 lb of soil loss per acre for the year's experiment.

Table VII. Average soil loss per nutrient source.

Nutrient Source[1]	Number of Plots	Maximum (lb)	Minimum (lb)	Total (lb)	Average (lb)
S	5	295.2	64.5	753.2	150.6
W	3	2555	134.9	2945	981.7
F	5	3584(1139)*	436	6841(3257)	1368(814)

* Parenthesis indicates neglecting plot no. 6

1 - S = Sludge
W = Primary wastewater
F = Fertilizer (15-15-15)

VEGETATION COMPOSITION AND PRODUCTIVITY

Composition analyses of the presence of vegetative species in percent were taken in September 1974 and June 1975 for plots 1-14. All plots responded favorably in producing a good vegetative cover except the control plot (Tables VIII and IX).

The three most prominent species observed in all plots in September 1974, except the control, were red clover, perennial ryegrass and tall fescue (Table VIII). Fourteen other species were observed in trace amounts. Red fescue and birdsfoot trefoil were identified but not prominent in most plots. This is probably due to the low seeding rate and the morphological characteristics of the red fescue and the crowding out of the naturally slow starting birdsfoot trefoil. In 1975, red clover was the dominant species with a number of other species present in much smaller percentages (Table IX). The overwinter changes indicated reductions in red clover and perennial ryegrass and increases in birdsfoot trefoil and other clover species. Low temperature sensitivity hindered the perennial ryegrass. Reduction in red clover percentages is related to the late harvest of the previous fall (October 1974).

A distinct purplish discoloration of the red clover plant leaves indicated a phosphorus deficiency in the plots receiving sludge (plots 3, 4, 8, 9 and 10). The affected plants were also shorter in height

Table VIII. Vegetation mixture composition in percent (20 September 1974).

Species	Plot Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Red clover	20	25	60	55	50	20	35	80	65	70	45	45	45	10
Perenial Ryegrass	40	30	20	20	20	30	30	15	20	15	40	30	20	X
Tall fescue	20	20	15	15	10	10	20	X	10	5	10	10	20	X
Red fescue		X			X									X
Birdsfoot trefoil	X	X	X	X	X	X				X		X		
Nutsedge	X	X	X	X	X					X				X
Barnyard grass		X	X			X								X
Plantain	X		X					X			X		X	X
Crabgrass	X		X		X	X	X					X		X
Foxtail	X	X	X	X	X			X	X	X	X	X	X	X
Other clovers		X		X	X		X			X	X	X	X	
Morning glory				X		X	X		X	X				X
Smart weed				X										
Quackgrass					X	X	X			X	X	X	X	X
Mustard								X	X	X		X		X
Fall Panicum							X							

X = Present in trace amounts

Table IX. Vegetation mixture composition in % (2 June 1975).

Species	Plot Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Red clover	40	40	50	45	30	20	30	50	50	20	30	40	60	10
Perennial ryegrass	5	10	15	15	20	5	5	10	15	10	10	15	5	
Tall fescue	25	25	10	10	10	10	5	10	15	25	10	10	5	5
Red fescue				5	X	X	X	X	X	X	X	X	X	
Birdsfoot trefoil	5	5	5	5	5		5							
Barnyard grass					X	X	X		X					
Other clovers	5	5	10	10	20	5	10	5	10	10	20	15	20	10
Morning glory						X				X				
Quackgrass				X	X	X	X	X	X	X	X	X	X	
Mustard			X											
Bluegrass				5	X	X	X	X	X	X	X	X	X	
Unindentified species						40	30			X	X	X	X	
Red canary										X				
Orchard grass												X		

X = Present in Trace Amounts

than plants growing in other plots. With the exception of plots 1, A and E, there is a strong correlation between productivity and nutrient source (15-15-15) fertilizer (Table X). The poor response on plots 1, A and E is probably due to the large amounts of gravel intermixed in the soil. In all three cases the amounts of erosion recorded visibly on plots A and E and measured on plot 1 (434 lb) were acceptable in comparison with the control (Table III).

A correlation appears between vegetation production and straw tacked with Terra Tack I for two of the nutrient sources that were not irrigated. A comparison of treatments 2 and 4 with treatments 7 and 11 shows that plots using straw tacked with Terra Tack I produced higher yields when not irrigated.

The productivity values for plots A through E which received five different erosion control treatments and fertilizer (15-15-15) with no irrigation are shown in Table X. The most productive treatments were B and C, with E being the lowest, and plots A and D being intermediate. Plot B, which produced the largest amount of vegetation, received direct runoff from the parking lot above the test area. This resulted in a large erosion gully through the center of the plot B (Figure 29). Plots C, D, and E which were treated with Terra Tack II directly on the bare soil (plot C), wood fiber mulch tacked with Terra Tack II (plot C), and straw tacked with latex (plot E) performed well in regard to vegetation production and visible sediment loss.

There was no general correlation between sediment loss and vegetation productivity except for the control plot which rated last in both production and soil loss (Table XI).

Figure 29. Erosion ditch through center of plot B.

Table X. Vegetation productivity.

Plot number	Dry Weight (lb/acre)	Soil loss (lb/acre)	Erosion Control	Nutrient Source	Total Moisture (in.)
Plot B	6202	----	TT II + S	F	33.1
2	5036	463.7	TT I + S	F	33.1
4	4995	64.5	TT I + S	S	33.1
5	4987	616.2	N	F	36.9
C	4822	----	TT II	F	33.1
7	4799	1037.9	TT I + S	F	36.9(I)
3	4683	154.0	JN	S	33.1
6	4370	3584.4	JN	F	36.9(I)
8	4187	295.2	N	S	36.9(I)
D	3900	----	TT II + WFM	F	33.1
11	3847	134.9	TT I + S	W	38.1(I)
A	3659	----	TT I + PN	F	33.1
9	3632	172.8	J	S	36.9(I)
1	3454	1039.2	JN	F	33.1
E	3394	----	L + S	F	33.1
10	3258	66.7	TT I + S	S	36.9(I)
13	2868	2555.4	N	W	38.1(I)
12	2352	254.7	JN	W	38.1(I)
14	936	34530.9	N	---	33.1

Key to Table X

TT II + S = Terra Tack II + Straw

TT II = Terra Tack II

N = No Erosion Control

JN = Jute Net

TT I + S = Terra Tack I + Straw

TT II + WFM = Terra Tack II + Wood Fiber Mulch

L + S = Latex + Straw

TT I + PN = Terra Tack I + Plastic Netting

F = Fertilizer (15-15-15)

S = Sludge

W = Wastewater (Primary)

(I) = Irrigated

Table XI. Soil loss vegetation productivity.

Plot Number	Soil Loss Dry Weight (lb/acre)	Plot Number	Vegetation Productivity Dry Weight (lb/acre)	
Plot 4	64.5	Plot 2	5036	
10	66.7	4	4995	
11	134.9	5	4987	I
3	154.0	7	4799	I
9	172.8	3	4683	
12	254.7	6	4370	I
8	295.2	8	4187	I
2	463.7	11	3847	I
5	616.2	9	3632	I
7	1037.9	1	3454	
1	1039.2	10	3258	I
13	2555.4	13	2868	I
6	3584.4	12	2352	I
14	34530.9	14	936	

I = Irrigated

SOIL TEMPERATURES

Soil temperatures were measured at 2 in. below the soil surface at three points along the long centerline of each plot at 10-ft intervals. A total of nine sets of readings were taken over the period of 15 July through 24 September. The mean of the three readings for each plot was taken as representative of the plot temperature.

The mean of each set of plot temperatures was compared to the individual plot temperatures to determine if any thermal gradient existed across the plots (from plot 1 to plot 14). In each of nine cases, all the plot temperatures were within $\pm$ 3 standard deviations of the mean, indicating no thermal gradient of any consequence.

The plot temperatures were ranked in order of descending temperature for each of the nine sets of readings, and then an overall rank was assigned to each plot, based on its nine ranks with respect to the other plots and the mean. This ranking was then compared to the nutrient source, the erosion control, the soil loss, and productivity. No correlation was found. The surface treatment (nutrient source plus erosion control) did not show any observable effect on the overall surface temperature. Neither did the overall surface temperature show any observable effect on vegetation productivity.

PLOT COST

The following cost analysis is based upon actual cost of material and estimated cost for labor. Table XII lists the individual costs for each treatment. Material costs such as grass seed, fertilizer, jute net, steel pins, straw, Terra Tack I, and Terra Tack II are represented as costs paid for during the construction of the site. Most items have increased in price since May 1974, such as grass seed from $36.60 to $92.50 per acre, fertilizer (15-15-15) from $24.38 to $64.77 per acre and jute netting from $1426.00 to $1982.00 per acre. The tacking compounds with the exception of the Dow latex were applied at double the manufacturer's recommended rate. Straw was applied at two tons per acre costing $67.50 per ton.

The cost of irrigation was estimated to be $50.00 per application. In this case the transportation cost was neglected because primary wastewater and water were available at the site. Sludge cost was estimated to be $20.00 for hauling and $100.00 for spreading with a manure spreader. The cost of hydromulching is increased or decreased depending on the material being spread. There is a $15.00 fertilizer spreading cost added to the fertilizer cost of $24.38 on plots B, C and D because Terra Tack II is not compatible with the fertilizer in a hydromulching mix. Thus, the fertilizer was spread in a separate operation.

Table XIII lists the individual treatments in ranking order on a cost per acre basis. For the treatments on plots 1-14 that were compared on sediment loss basis, the irrigated plots using jute netting are the most expensive, followed by the irrigated plots. The least expensive are plots 2 and 4 using straw tacked with Terra Tack I and fertilizer with 15-15-15 fertilizer and sludge. For the general testing on plots A-E the least expensive was plot C where the bare soil was tacked with Terra Tack II. This was followed by the latex treated plot costing $347.23 per acre. Plots D and B using straw and wood fiber mulch were slightly more expensive than plot E but considerably less than plot A using the plastic netting. Generally, the treatments on A-E were less expensive than the treatments on 1-13 with the exception of plots 2 and 4. This was due mainly to the irrigation of plots 5-13 and the use of jute netting on plots 1, 3, 6, 9 and 12.

SUMMARY

A terrain stabilization research/demonstration site was constructed in May 1974 at Hanover, New Hampshire, to investigate various combinations of physical, chemical and biological techniques for terrain stabilization in cold regions. Fourteen test plots (10 x 40 ft) with individual 350-gal. tanks to collect sediment and runoff water were installed on a 16°

Table XII. Material and labor cost for individual treatments (per acre).

Plot 1

Seed	$ 36.60
Net + Pins	1,426.00
Spread Fertilizer and Seed	25.00
Fertilizer	24.38
Net Labor	90.00
	$1,601.98

Plot 2

Seed	$ 36.60
Fertilizer	24.38
Terra Tack I	80.00
Straw	135.00
Hydro-Mulch	50.00
	$325.98

Plot 3

Seed	$ 36.60
Haul Sludge	20.00
Net + Pins	1,426.00
Net Labor	90.00
Spread Sludge	100.00
Spread Seed	15.00
	$1,687.60

Plot 4

Seed	$ 36.60
Truck Sludge	20.00
Terra Tack I	80.00
Straw	135.00
Spread Sludge	100.00
Hydro-Mulch	50.00
	$ 421.60

Plot 5

Seed	$ 36.60
Fertilizer	24.38
Hydro-Mulch	16.66
Irrigate	950.00
	$1,027.64

Plot 6

Seed	$ 36.60
Fertilizer	24.38
Spread Fertilizer and Seed	25.00
Jute Net + Pins	1,426.00
Irrigate	950.00
Net Labor	90.00
	$2,551.98

Plot 7

Seed	$ 36.60
Fertilizer	24.38
Hydro-Mulch	50.00
Terra Tack I	80.00
Straw	135.00
Irrigate	950.00
	$1,275.98

Plot 8

Seed	$ 36.60
Truck Sludge	20.00
Spread Sludge	100.00
Irrigate	950.00
Seed Labor	15.00
	$1,121.60

Plot 9

Seed	$ 36.60
Truck Sludge	20.00
Spread Sludge	100.00
Irrigate	950.00
Net + Pins	1,426.00
Net Labor	90.00
Seed Labor	15.00
	$2,637.60

Plot 10

Seed	$ 36.60
Terra Tack I	80.00
Straw	135.00
Truck Sludge	20.00
Irrigate	950.00
Spread Sludge	100.00
Hydro-Mulch	50.00
	$1,371.60

Plot 11

Seed	$ 36.60
Terra Tack I	80.00
Straw	135.00
Irrigate	1,250.00
Hydro-Mulch	50.00
	$1,551.60

Plot 12

Seed	$ 36.60
Net + Pins	1,426.00
Net Labor	100.00
Irrigate	1,250.00
Seed Labor	15.00
	$2,827.60

Plot 13

Seed	$ 36.60
Irrigate	1,250.00
Seed Labor	15.00
	$1,301.60

Plot 14

No Labor
or
Material

Table XII (con't)

Plot A

Terra Tack I	$ 80.00
Seed	36.60
Plastic Netting	653.40
Fertilizer	24.38
Hydro-Spray	16.66
	$ 811.04

Plot B

Seed	$ 36.60
Terra Tack II	202.50
Straw	135.00
Fertilizer and Spreading	39.38
Hydro-Mulch	50.00
	$ 463.48

Plot C

Seed	$ 36.60
Terra Tack II	202.50
Fertilizer and Spreading	39.38
Hydro-Spray	16.66
	$ 294.48

Plot D

Seed	$ 36.60
Terra Tack II	202.50
Wood Fiber Mulch	105.00
Fertilizer and Spreading	39.38
Hydro-Mulch	50.00
	$ 433.48

Plot E

Chemical	$ 101.25
Seed	36.50
Straw	135.00
Fertilizer	24.38
Hydro-Mulch	50.00
	$ 347.23

Table XIII. Plot cost ranking.

Plot Number	Cost/acre	Soil loss (lb/acre)	Erosion Control	Nutrient Source	Vegetation Prod. (lb/acre)	Total Moisture (in.)
C	$ 294.48	---	TT II	F	4822	33.1
2	325.98	463.7	TT I + S	F	5036	33.1
E	347.23	---	L + S	F	3394	33.1
4	421.60	64.5	TT I + S	S	4995	33.1
D	433.48	---	TT II + WFM	F	3900	33.1
B	463.48	---	TT II + S	F	6202	33.1
A	811.04	---	TT I + PN	F	3659	33.1
5	1,027.64	616.2	---	F	4987	36.9 (I)
8	1,121.60	295.2	---	S	4187	36.9 (I)
7	1,275.98	1037.9	TT I + S	F	4799	36.9 (I)
13	1,301.60	2555.4	---	W	2868	38.1 (I)
10	1,371.60	66.7	TT I + S	S	3258	36.9 (I)
11	1,551.60	134.0	TT I + S	W	3847	38.1 (I)
1	1,601.98	1039.2	JN	F	3454	33.1
3	1,687.60	154.0	JN	S	4683	33.1
6	2,551.98	3584.4	JN	F	4370	36.9 (I)
9	2,637.60	172.8	JN	S	3632	36.9 (I)
12	2,827.60	254.7	JN	W	2352	38.1 (I)

Key to Table 13

TT I + S = Terra Tack I + Straw
TT II = Terra Tack II
L + S = Latex + Straw
TT II + WFM = Terra Tack II + Wood Fiber Mulch
TT II + S = Terra Tack + Straw
TT I + PN = Terra Tack I + Plastic Netting
JN = Jute Netting

F = Fertilizer (15-15-15)
S = Sludge
W = Primary Wastewater
(I) = Irrigated

slope (Fig. 1). In 13 of the 14 plots the variables studied were nutrient source (fertilizer, sludge and primary wastewater), moisture (irrigated and nonirrigated), erosion control material (jute netting and straw tacked with a tacking compound), and vegetation (three grasses and two legumes). The control plot (14) was left bare of seed, fertilizer and erosion control material for comparison. A 20,000-ft^2 area adjacent to the 14 plots was reshaped for general testing of various combinations of tacking chemicals, plastic netting, straw and wood fiber mulch.

Climatological analysis for the test site shows that: 1) the total accumulated precipitation amounts remained below normal throughout the experiment, 2) the total accumulated precipitation amount at the CRREL site was 33.10 in., which is 6.40 in. less than normal for the period studied, and 3) the average air temperature for the entire test period was nearly normal; however, individual months deviated as much as 6°F from the long-term normal.

In general, all treatments with exception of plots 6 and 13 were effective in reducing soil loss in comparison with the control plot which had a loss of 34,531 lb of soil (dry weight) on a per acre basis. The effectiveness of treatment based on comparison of the soil loss for the individual treatment against the control plot ranged from 89.6% on plot 6 to 99.8% on plot 4 (Table III). If plot 6 is neglected because of the problem with the seal between the lip of the tank and the plot, the range of effectiveness against the control is 92.6% on plot 13 to 99.8% on plot 4 (Table III).

There is strong indication from the data collected on sediment loss that the sludge is acting both as a nutrient source and as an erosion control material (net) by reducing runoff velocity and absorbing moisture (Table III). The effectiveness of sludge as an erosion control material is further emphasized by comparing soil loss per parameter as shown in Tables IV, V and VI. In each case considered, the sludge treated plots were the most effective. If the soil loss is considered as a function of the nutrient source in groups, the sludge-treated plots average 150 lb, the fertilized plots 814 lb (neglecting plot 6) and the wastewater plots 981.7 lb of soil loss per acre.

All plots except the control responded favorably in producing a good vegetative cover (Tables VIII and IX). The three most prominent species observed in the first growing season were red clover, perennial ryegrass and tall fescue. The analyses completed in June 1975 indicated red clover to be the dominant species with a number of other species present in much smaller percentages (Table IX). There was no general correlation between sediment loss and vegetation production with the exception of the control (Table XI).

Soil temperatures were measured at 2 in. below the surface on the 14 plots. There was no indication that the various soil treatments influenced the soil temperatures, nor was there any indication that the soil temperatures influenced the vegetation production on any of the 14 plots.

The cost analysis indicated that the irrigated plots cost $950 (water) and $1250 (primary wastewater) more than nonirrigated plots (Table XII). For erosion control-nutrient pairs the soil loss data (Table III) indicated that irrigated plots lost more soil than nonirrigated plots (1,2,3, and 4).

The plots that were treated with jute netting were the most expensive ($1426.00) and plot 3, which was topdressed with sludge, was the most effective of the jute net treated plots against sediment loss (Table III).

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APPENDIX A

Chemical Analysis of Water Sample

A set of runoff samples was obtained from each collection tank following three major storms on 18 July 1974, 1 October 1974, and 29 May 1975. The 18 July 1974 sample was analyzed for total phosphorus, Kjeldahl nitrogen, nitrate nitrogen and ammonium. Subsequent sets were analyzed for pH, conductivity, organic carbon, inorganic carbon, total carbon, total phosphorus, chloride content, Kjeldahl nitrogen, nitrate nitrogen, and ammonium.

APPENDIX A

PLOTS July 18, 1974		pH 1	Cond μmhos 2	C_o ppm 3	C_I ppm 4	C_T ppm 5	P_T ppm 7	Cl ppm 8	N_K ppm 9	NO_3 ppm 10	NH_4 ppm 11
Fertilizer	1						<D		12.5	.58	8.5
"	2						<D		9	.35	6.5
Sludge	3						<D		5	.36	3.5
"	4						<D		5	.29	3.5
Fertilizer	5						<D		7	.18	5.5
"	6						<D		9.5	.16	9
"	7						<D		3.5	.43	3
Sludge	8						<D		4.5	.21	3.5
"	9						<D		4.5	.29	3
"	10						<D		3.5	.32	2.5
Wastewater	11						<D		3.5	.30	3
"	12						<D		4	.32	3.5
"	13						<D		4	.15	3.5
Nothing	14						<D		2	.15	2
<u>October 1, 1975</u>											
Fertilizer	1	6.8	169	40	10	50	<D	12.75	3	.1	2
"	2	6.7	140	51	11	62	<D	13.75	2.5	<D	1.5
Sludge	3	6.7	100	43	9	52	<D	6.75	1.5	8	1
"	4	6.8	105	32	8	40	<D	8.75	1	.1	1
Fertilizer	5	6.7	170	88	12	100	<D	12.25	6.5	.1	4
"	6	6.7	360	3	7	10	<D	34	3	2.1	3
"	7	6.8	160	40	10	50	<D	16	3.5	<D	2
Sludge	8	6.6	110	38	10	48	<D	8.25	4	<D	2
"	9	6.7	120	33	9	42	<D	7.5	4	1.4	3.5
"	10	6.5	140	61	11	72	.5	12.25	5.5	.8	5.5
Wastewater	11	6.7	190	76	14	90	<D	15.75	9.5	<D	3
"	12	6.5	225	108	16	124	.5	20	10	<D	4.5
"	13	6.7	165	73	15	88	<D	13.5	7.5	.4	11.5
Nothing	14	10.4	2700	56	106	162	<D	6.5	3	1.3	2.5
<u>May 29, 1975</u>											
Fertilizer	1	7.3	150	9.5	20.5	30	<D	1.5	One	<D	<D
"	2	7.3	20	7.5	3	10.5	<D	<D	.5	<D	<D
Sludge	3	7.6	30	7.5	3.5	11	<D	<D	.5	<D	<D
"	4	7.2	60	14.5	3.5	18	2	One	One	<D	<D
Fertilizer	5	7.2	250	80	19.5	99.5	.25	11	11	1.48	6.5
"	6	7.4	740	81	66	147	.25	9.5	8	D	3.5
"	7	6.9	180	36	20	56	.25	6	6.5	1.76	6.5
Sludge	8	7.4	40	14.5	4	18.5	4.5	1.5	.4	<D	One
"	9	6.7	130	59.5	11	70.5	One	6.5	7	.83	3
	10	7.0	100	49	11	60	<D	5	6	.74	3.5
Wastewater	11	7.3	40	12.5	5.5	18	5.25	6	One	.2	One
"	12	7.3	110	78.5	11.5	90	.5	8.5	6.5	D	2.5
"	* 13	7.0	700	33	49	82	<D	8	4.5	2.97	2.5
Rainwater	14	7.9	30	1.5	1.5	3	<D	<D	<D	.72	.5

*NOTE: Plot 13 sample spilled